

## TWO CLASSES OF GAMMA-RAY BURSTS

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## ABSTRACT

We have studied the duration distribution of 222 Gamma Ray Bursts of the first BATSE catalog. We find a bimodality in the distribution, which separates GRBs into two classes: short events ( $< 2$  s) and longer ones ( $> 2$  s). Both sets are distributed isotropically and inhomogeneously in the sky. We find that their durations are anti-correlated with their spectral hardness ratios: short GRBs are predominantly harder and longer ones tend to be softer. Our results provide a first GRB classification scheme based on a combination of the GRB temporal and spectral properties.

## 1. INTRODUCTION

Gamma-Ray Burst (GRB) studies over the last 20 years have not succeeded in revealing tell-tale properties that would help identify the nature of their emission sites. Moreover, there exist no concrete counterpart identifications in any other wavelength within the well-defined GRB error boxes (Hurley 1991 and references therein) that would point towards a known parent population for the phenomenon. Recent results (Meegan et al. 1991) from the Burst and Transient Source Experiment (BATSE) (Fishman et al. 1989) on the Compton Gamma-Ray Observatory (CGRO) have shown that the sky distribution of the GRB sources is isotropic, but not homogeneous. Any attempt to identify GRB subclasses based on similarities in their spatial, spectral or morphological properties has failed so far (Briggs et al. 1993, Fishman et al. 1993). We present here a study of one of the GRB global properties, namely their duration distribution, which has led to the confirmation of their division into two subclasses. This duration bimodality is linked for the first time with a different average spectral hardness associated with each class.

## 2. DURATION DISTRIBUTION

The distribution of GRB durations has been studied extensively in the past (Cline and Desai 1974, Mazets et al. 1981, Norris et al. 1984, Klebesadel 1990, Hurley 1991). Most studies agree that there is a hint of bimodality with the separation being in the 0.5 - 4 s range. There are several reasons why the previous data sets could not establish the bimodal nature of the distribution: lack of instrument trigger sensitivity to short events, low temporal resolution, difficulty of confirmation of a very short event as a burst in an often noisy data set, etc. They have all led to biases against detection of short events. The first BATSE catalog (Fishman et al. 1993) presents a complete, confirmed set of 260 GRBs, detected with unprecedented sensitivity over the instrument's first year of operation (April 21, 1991 to March 5, 1992).

The criteria for determining a GRB duration have (widely) varied over the past, without an accepted consensus for a "duration algorithm". We have introduced (Kouveliotou et al. 1993) an unbiased and reproducible way of estimating durations. We define  $T_{90}$  as the time during which the cumulative counts increase from 5% to 95% above background, thus encompassing 90% of the total GRB counts.  $T_{50}$  is defined similarly to include 50% of the counts.

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The times thus defined are an intensity independent measure of duration, unlike previous definitions. In most cases the data available afforded very accurate measurements for both times. This procedure failed whenever there existed data gaps during a burst readout. Thus, out of the 260 GRBs contained in the first BATSE catalog, we have  $T_{90}$  and  $T_{50}$  values for 222.

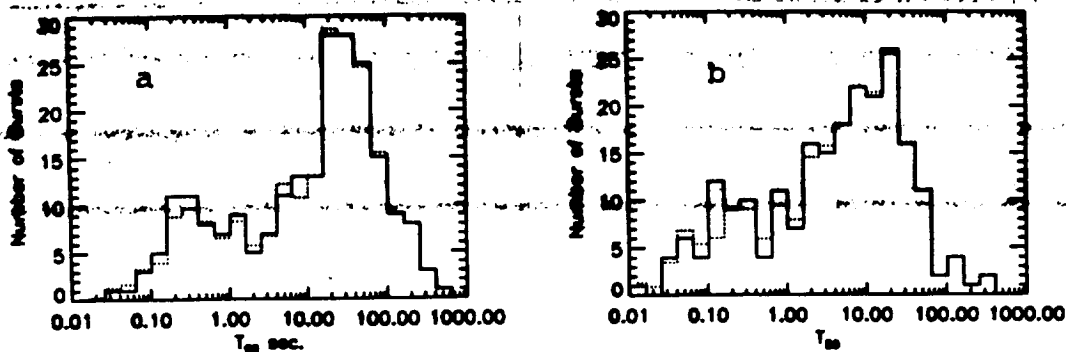


Figure 1. a) Distribution of  $T_{90}$  for the 222 GRBs of the first BATSE catalog. b) Distribution of  $T_{50}$  for the same GRB set. Solid lines are the histograms of the raw data; dotted lines are the error-convolved histograms as explained in the text.

The solid line in Figure 1a shows the uncorrected distribution of the 222 values for  $T_{90}$ . To account for the time errors  $\delta T_{90}$  in each histogram bin, we have assumed that each  $T_{90}$  is represented by a Gaussian of standard deviation given by  $\delta T_{90}$ . Each error-convolved histogram bin is then derived by adding the overlapping areas of all Gaussians that fall within its boundaries. The convolved distribution is plotted with a dotted line on Figure 1a: we notice that the inclusion of the errors has expanded the short duration range (where the uncertainties are larger), but has not affected the longer duration bursts.

Both distributions of Figure 1 show a dip around 2 seconds. The dip is not an instrumental artifact: BATSE's trigger sensitivity is maximum near 1 s, which is its longest trigger timescale. Although it is difficult to quantitatively assess the statistical significance of the dip, we estimate that convex, unimodal distributions are rejected at the 2-3  $\sigma$  level. We have fit a quadratic function between the two peaks in the histogram and determined its minimum to be at  $T_{90} = 1.2 \text{ s} \pm 0.4 \text{ s}$ , which rounded off to the next integer bin edge, is 2.0 s. This effectively divides the 222 GRBs into two subsets: one containing 58 short events ( $T_{90} < 2.0$  seconds) with a logarithmic mean  $T_{90}$  of  $0.33 \text{ s} \pm 0.21 \text{ s}$  and a second of 164 longer GRBs with a mean of  $26.2 \text{ s} \pm 1.7 \text{ s}$ .

The fraction of short events in the data bases derived with various experiments does not seem to vary significantly: SIGNE (on Venera 11-12) reports 25% (Diyachkov et al. 1980), the International Sun Earth Explorer-3 (ISEE-3) shows 29% (Norris et al. 1984), albeit with a limited sample, the Phebus instrument on Granat has 27% (Dezalay et al. 1991), and for BATSE the same fraction amounts to 26% of the first catalog data. The KONUS experiments on Venera 11/12 and 13/14, however, show significantly smaller percentages, 7% and 16%, respectively. One explanation of this discrepancy could be the detection threshold for the KONUS experiments, which increased with decreasing GRB duration (Mazets et al. 1981).

Comparison of the duration distributions obtained by previous observers (see Hurley 1991) with the  $T_{90}$  distribution shows that the BATSE data have a factor of 2 higher average durations. The arithmetic mean of the  $T_{90}$  values is  $37.6 \text{ s} \pm 2.7 \text{ s}$  vs the mean of 18.3 s for 616 GRBs compiled by Hurley (1991). One possible explanation of this shift in mean duration could be a systematic effect of instrumental sensitivity. BATSE, with its unprecedented

sensitivity, would see what previous experiments would have called an average GRB for a much longer time. If that is indeed the case, raising the instrument sensitivity would bring the average duration to a lower value. The  $T_{50}$  distribution for the same 222 GRBs (Figure 1b) effectively, does this. We notice that the average value of  $T_{50}$  is  $16.3 \pm 1.0$  s, similar to KONUS and half of that for BATSE's  $T_{90}$ 's. Hence what we see is a convincing effect of different detection thresholds on the GRB durations, which strengthens the case of using a single experiment to derive statistics on GRB duration distributions. We also notice that the duration bimodality is not as significant in the  $T_{50}$  distribution; this again is consistent with a "tip of the iceberg" effect. We have searched for clusterings in the burst arrival times for short and long events: both samples are entirely consistent with Poisson distributions. The arrival rates are 0.2 and 0.8 per day for the short and long GRBs, resp.

In the following we will consider the set of the 58 short GRBs with  $T_{90} < 2$  s as a different class and study their global properties.

### 3. SPATIAL DISTRIBUTIONS: Isotropy and Homogeneity tests

Figure 2 shows the sky distribution of the short events; although the sample is limited we can still see that their distribution is isotropic. The values of their various dipole and quadrupole statistics differ in most cases by about 1 standard deviation or less from the values expected for isotropy (Kouveliotou et al. 1993). We have also examined the distribution of the angular separations of GRB pairs and found no evidence for clustering.

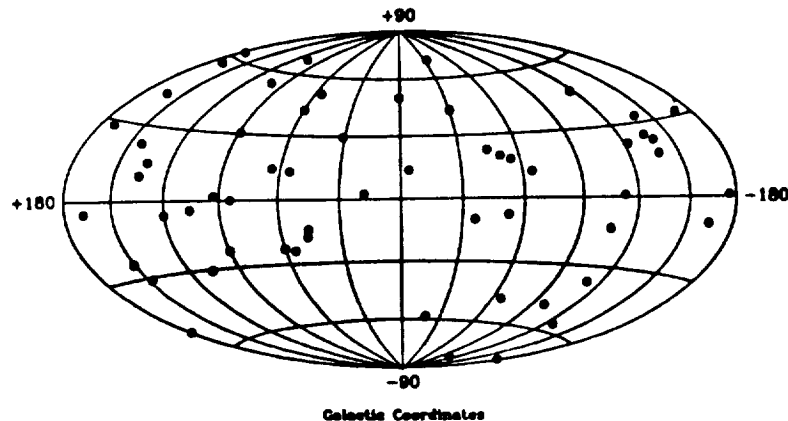


Figure 2. The sky map distribution of the 58 short ( $< 2$  s) GRBs

Similarly, the statistics of the longer events are consistent with an isotropic distribution as expected from the overall isotropy of the 260 GRBs from the first BATSE catalog (Fishman et al. 1993).

Whenever we have data gaps during a burst accumulation we do not compute the  $V/V_{max}$  for the event, as is explained in Fishman et al (1993). We have both  $T_{90}$  and  $V/V_{max}$  values on the 64 msec trigger timescale for 48 short events and 100 long ones. The  $\langle V/V_{max} \rangle$  values are  $0.302 \pm 0.038$  and  $0.367 \pm 0.030$ , resp. There is no significant difference between the two means: they are consistent with each other and both are inconsistent with homogeneity. The same trend is evident from Figure 3, which shows the  $\log N$ - $\log P$  diagram for the short (58) and long (164) GRB sets, together with a homogeneous distribution (dashed line). We conclude that both sets are isotropic and inhomogeneous, in agreement with the overall BATSE GRB results.

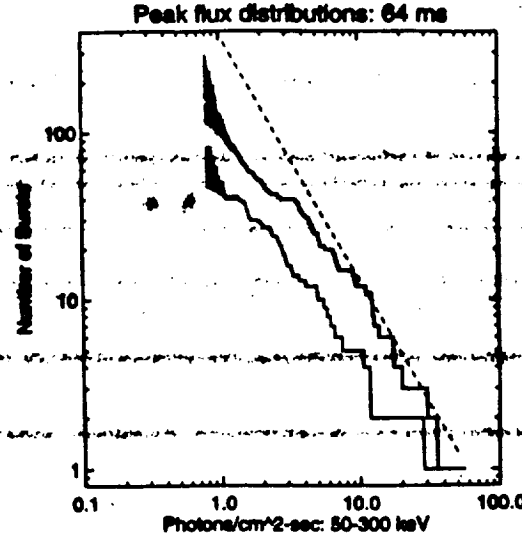


Figure 3. Log N - log P distributions for the long (upper curve) and for the short (lower curve) GRBs. The dashed line indicates a homogeneous distribution. The peaks are integrated with 64 ms over 50 - 300 keV. The shaded regions represent the range of earth scattering corrections.

#### 4. HARDNESS RATIOS vs $T_{90}$

We have integrated the counts above background during  $T_{90}$  for the 222 GRBs in four discriminator channels with energy ranges of 25 - 50, 50 - 100, 100 - 300 and > 300 keV. We define as  $HR_{32}$  the ratio of total counts in the 100 - 300 keV and 50 - 100 keV energy range. Figure 4 (right pannel) shows the scatter plot of the hardness ratios  $HR_{32}$  vs  $T_{90}$ . The Spearman Rank-Order correlation coefficient (Press et al. 1993) between  $HR_{32}$  and  $T_{90}$  is  $-0.375$ ; the probability of a fluctuation causing a chance correlation at this level is  $\sim 10^{-8}$ . The density distributions of the hardness ratios are shown as two histograms in the left pannel of Fig 4. Short events are predominantly harder, while longer events are predominantly softer, as expected from the high correlation between hardness ratios and durations. The same trend is seen with the  $HR_{3/21}$  distribution.

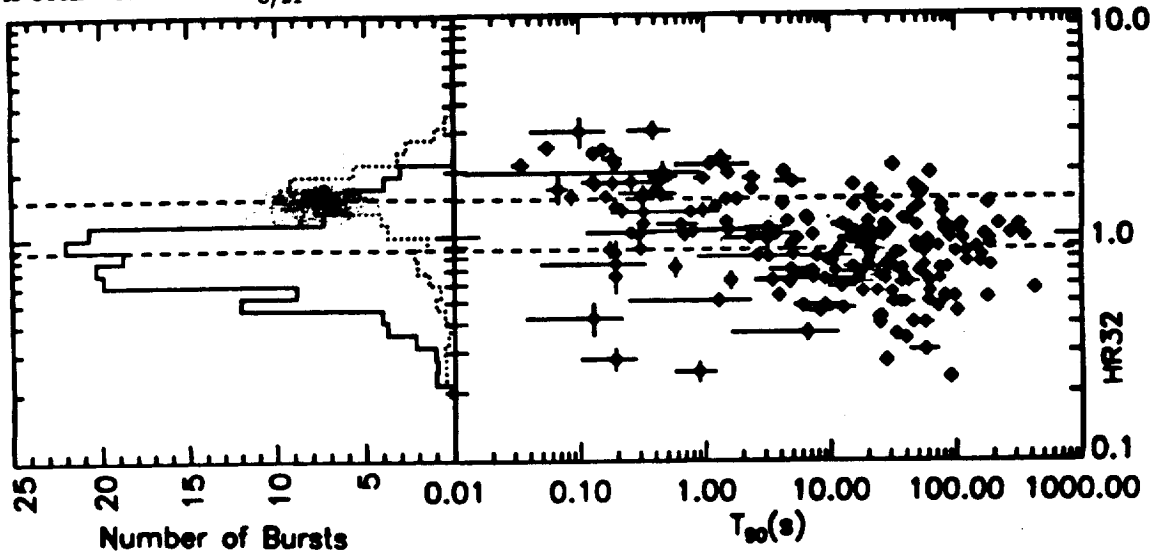


Figure 4. Left: Hardness ratio histograms for events with  $T_{90} > 2$  s (solid line) and  $< 2$  s (dotted line). Right : Hardness ratios  $HR_{32}$  vs  $T_{90}$  scatter plot. The dashed lines on both

plots correspond to the mean hardness ratio of the two duration classes.

The values for the mean of the  $HR_{32}$  calculated separately for the two GRB classes previously identified are  $1.49 \pm 0.08$  and  $0.87 \pm 0.03$  for  $< 2$  and  $> 2$  s, respectively. The values for the short events are clearly higher than the ones for the longer events. This result has also been seen in the Phebus data (Dezalay et al. 1991), albeit between higher energy ranges (0.3-7 MeV to 100-300 keV). Dezalay et al., however, were unable to detect a duration bimodality in their small sample of 66 GRBs. We believe that our data confirm these earlier results and provide the first evidence of the continuity of the hardness-duration correlation over the whole GRB observable spectrum.

## 5. DISCUSSION

We have linked here for the first time the duration bimodality with the hardness-duration correlation of GRBs. Previous studies have reported evidence for either the former (Cline and Desai 1974, Mazets et al. 1981, Klebesadel 1990, Norris et al. 1984, Hurley 1991) or the latter (Dezalay et al. 1991). Our study shows that the two classes separated by duration are also associated with significantly different average hardness ratios. We find that the short events have the same peak intensity range as the longer ones; this makes the total amount of energy released by the two types significantly different. Both short and long GRBs have isotropic but inhomogeneous spatial distributions. All evidence suggests that both GRB subsets originate from the same type of objects. Different geometries of their emission sites (with respect to the observer) may be responsible for the spectral and temporal differences between the classes.

## ACKNOWLEDGEMENTS

We wish to express our thanks to Bohdan Paczynski, Jan van Paradijs and Gerry Share for fruitful discussions and to J. Ostriker for suggesting to us the  $T_{50}$  algorithm as a measure for the GRB durations.

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